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Design of DC-DC Boost Converter with Negative Feedback Control for Constant Current Operation

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ABSTRACT

In this paper design of DC-DC boost converter with constant current control, charging is presented to charge the battery of electric vehicles. The different methods of battery charging are discussed. The charging profile of different types of batteries is investigated and compared with respect to charging time. The battery current is sensed and compared with a reference current and the generated actuating signal which is an error is feed to PI controller to compute a duty cycle of boost converter for constant current operation. A 6 V dc supply is obtained by using a step down transformer and diode rectifier. Boost converter parameters are designed for continuos conduction mode operation. The limiting values of duty cycle are fixed in the range of 0.5 to 0.6 for constant current operation. Simulation is carried out using MATLAB software for constant current operation connected to a 50 Ah, 12 V battery load. The constant current operation is achieved using negative feedback control. The switching frequency of boost converter is set to 20 kHz. The filter components are also designed to reduce ripple content within limited values. The simulation result shows the effectiveness of charging control for hardware implementation.

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1. INTRODUCTION

As we know that the fuel consumption is increasing day by day and cause an environmental problem [1]. The demand for electric energy is more but supply is limited. Further, the green house effect causes global warming which is a very serious issue all are facing. The only solution is renewable energy but it has its own limitation. It is not available for 24 hrs. The chargeable battery is the best solution for energy crisis and global warming. Therefore researchers are moving towards the automobiles which don’t cause any pollution and keep the environment clean [2]-[3]. Electric vehicles (EVs) and plug in hybrid electric vehicles (PHEV) are in more demand as they reduce fuel usage and green house emission [4]-[6]. The state of art for electrical vehicle is briefly discussed in literature [7]. The battery is one of the important parts of an electric vehicle. Most of the EVs are powered by 12-volt lead acid battery. The battery can be charged by different control method like constant current charging, constant voltage charging, two step charging, pulse charging and reflex charging. The pulse charging control of battery is discussed for lead acid battery [8]. Here isolated phase shift full bridge converter is used to charge the battery. In [9] the new digital-controlled technique is used to charge the battery with both constant current and constant voltage control method. In this method, no current feedback is required. When the voltage reaches the preset value using constant current charge, the

charging operates at constant voltage mode. In [10] reflex charging method is discussed with shows low stress and high efficiency. Reflex charging method is better than pulse charging method.
In this paper DC-DC converter is used to charge the battery by using constant current charging control. DC-DC converters play important role in charging and discharging of the battery. It act as an interface between source and load. There are two type of DC-DC converter isolated and non-isolated. Isolated converters are buck, boost, buck-boost, cuk, zeta and sepic converter and non-isolated converters are fly back, full bridge, half bridge, and forward converters. All converters have different operating principle, advantages, and disadvantages [11].
The charging characteristics of battery depend upon the type of charging. There are different control methods of battery charging. Each method has its own significance which is given here.
a. Constant current charging:
This is a very simple method of charging the battery. A constant current is used to charge the battery and voltage is increased up to its desired preset value. However, if the battery is over charged it will degrade the life of the battery.
b. Constant voltage charging:
In constant voltage charging technique for battery charging can be easily implemented with simple control method. In constant voltage charging method, the voltage is fixed to the desired and not allowed to change, however value of the current decreases. When current reach the below the threshold value the charging is completed.
c. Two stage charging:
Figure 1 shows the two stage charging profile of battery. This method is the combination of constant current and constant voltage charging. In first stage, battery is charged by constant current until the battery voltage reached to a reference value. When a voltage is reached the desired value, constant voltage charging started. In this mode, current starts decreasing up to the threshold value.

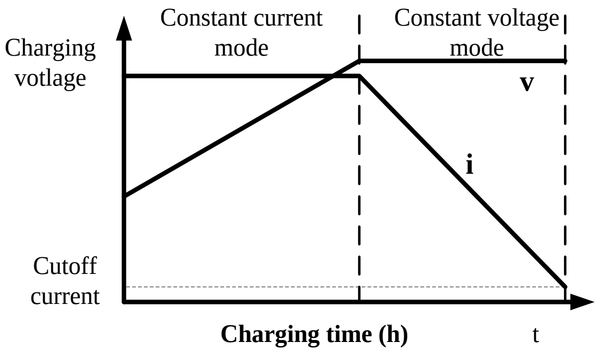

Figure 1. Constant current and constant voltage battery charging profile.

d. Pulse charging
Figure 2(a) shows the pulse charging characteristic. In this method, current pulses are applied to the battery periodically. It consists of positive pulse for Ton time and zero pulse for Toff time. This method increases the life of battery and reduces the charging time.

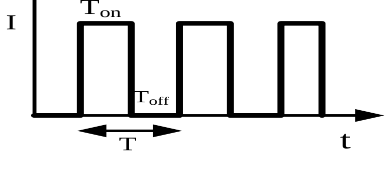

Figure 2(a). Pulse charging current waveform.

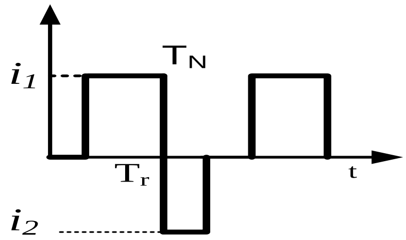

Figure 2(b). Reflex charging current waveform.

e. Reflex charging

An improvement on pulse charging is obtained by reflex charging. The reflex charging method consists of both positive and negative pulses along with resting period. The positive pulse is the charging period of battery, negative pulse is discharging period of battery whereas zero pulse is a relax time or delay time. Figure 2(b) shows the charging characteristic of reflex charging.

Figure 3 shows the block diagram of constant current charging scheme. It consists of ac grid, rectifier, boost converter, PI controller and battery load. The circuit diagram of boost converter employing battery charging system is shown in Figure 4. The grid voltage is step down by the transformer. The output of transformer is then fed to the diode bridge rectifier which converts ac to dc power. The rectifier output is then fed to DC-DC boost converter to and control the output voltage which can be used for battery charging. The PI controller is used to control duty cycle of switching pulses applied to switch of boost converter for constant current operation.

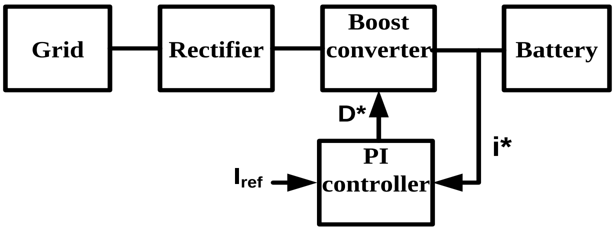

Figure 3. Block diagram of a constant current control battery charging system.

The output voltage of boost converter is given by

$$V_{in} = \frac{1}{1-\delta} V_{out} \tag{1}$$

Where V_{out} is output voltage, δ is duty ratio and V_{in} is input voltage.

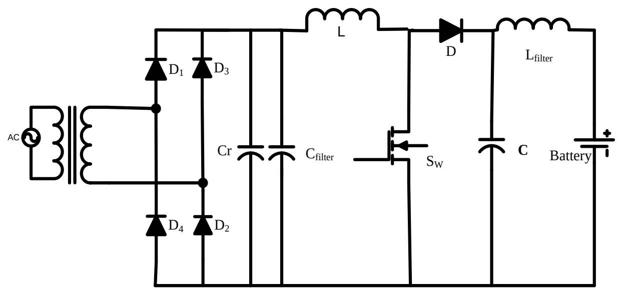

Figure 4. Circuit diagram of a proposed charging system.

This paper proposes the design of boost converter for constant current charging control by using negative feedback with PI controller. Section 2 describes the design of boost converter parameters along with rectifier and filter components. Section 3 deals with control technique applied for constant current charging. Section IV deals with the simulation of constant current charging control operation. Section V presents the detailed simulation results obtained for constant current operation of battery charging.

2. DESIGN OF BOOST CONVERTER

The design of boost converter charging system basically consists of rectifier design, boost converter design and filter design. It is carried out by assuming percent of ripples in voltage and current waveform respectively.

Table 1. Design specification of boost converter

Sr. No	Specifications	Values
1	Power (P)	90 W
2	Output voltage, (V_{out})	12 V
3	Output current, (I_{out})	7.5 A
4	Input current (I_{in})	15A
5	Input voltage (V_{in})	6V
6	Switching frequency (f)	20 kHz

Table 2. Boost Converter design parameter

S. No	Components	Value
1	Boost inductor, (L)	100 µH
2	Boost capacitor, (C)	1.5625 mF
3	Boost Diode, (D)	50 V
4	Filter Inductor, (L_{filter})	1 µH
5	Filter capacitor, (C_{filter})	156.25 µF
6	Rectifier Capacitor, ($C_{rectifier}$)	2.5125 F
7	Transformer, (T)	150 230/6 V

2.1. Boost converter design

Boost converter consist of inductor, capacitor, switch and diode [12]. . The input pulses of switch are controlled by using PI controller. The input to boost converter is 6 V and output is stepped up in the voltage range of 12-13 V. Power rating of boost converter is 90 W, assuming loss less converter.

Input voltage (V_{in}) is 6 V

Output voltage (V_{out}) is 12V

Therefore input current $I_{in} = \frac{90}{6} = 15$ A

Output current $I_{out} = \frac{90}{12} = 7.5$ A

Desired current ripple $K_i = 10\,\%$

Desired output voltage ripple $K_v = 1\,\%$

When switch is in ON state

$$V_{in} = L\frac{di}{dt} = L\frac{\Delta I_{in}}{T_{on}}$$

$$V_{in} = L\frac{K_i I_{in}}{\delta T}\ , \quad L = \frac{V_{in}\delta}{f K_i I_{in}} = 100\ \mu\text{H}$$

When switch is in OFF state

$$I_{out} = C\frac{dv}{dt} = C\frac{\Delta V_{out}}{T_{off}}$$

$$I_{out} = C\frac{K_v V_{out}}{(1-\delta)T} \quad , \quad C = \frac{I_{out}(1-\delta)}{fK_v V_{out}} = 1.5625 \text{ F}$$

3.2. Filter design

Filter is inserted in the circuit to avoid the ripple of voltage and current. Capacitor filter is inserted to remove the voltage ripple in input side and inductor filter is used to remove the ripple in output current. For effective filter design the charge (ΔQ) should get stored in capacitor and should get released back to the load when current is below desired value. Same case with inductor the flux (ΔΨ) should get stored in filter inductor and should be available when voltage is less. The charge and flux storing time duration is shown in Figure 6.

$$\Delta Q = \frac{1}{2}\times\frac{T_{on}}{2}\times\frac{\Delta I}{2}+\frac{1}{2}\times\frac{T_{off}}{2}\times\frac{\Delta I}{2}$$

$$\Delta Q = \frac{\Delta I}{8}\times(T_{on}+T_{off}) = \frac{\Delta I}{8f}$$

$$C_{filter} = \frac{K_i I_{in}}{8fK_v V_{in}} = 156.25 \ \mu\text{F}$$

Similarly

$$\Delta\psi = \frac{1}{2}\times\frac{T_{on}}{2}\times\frac{\Delta V}{2}+\frac{1}{2}\times\frac{T_{off}}{2}\times\frac{\Delta V}{2}$$

$$\Delta\psi = \frac{\Delta V}{8}\times(T_{on}+T_{off})$$

$$L_{filter}\Delta I_{out} = \frac{\Delta V}{8}\times(T_{on}+T_{off}) = \frac{\Delta V}{8f}$$

$$L_{filter} = 1 \ \mu\text{H}$$

4. CONTROL TECHNIQUE FOR CONSTANT CURRENT CHARGING

In this paper boost converter is operated in continuous conduction mode. This converter is used to charge the battery at constant output current and also to maintain the output voltage at desired value in the constant current mode of operation and constant voltage after SOC is reached 80% to prevent the battery from over charging. Although controller discussed in [13-17] are helpful for controlling boost converter for voltage control and constant current with negative feedback control. In this system, the output current is sensed and compared with the reference current and the error signal e (t) is feed to PI controller.

$$e(a) = K_p \times e(t) + K_I \int e(t)dt \qquad (2)$$

Where K_P is proportional constant and K_I is integral constant and e (t) is error signal given by

$$e(t) = I_{ref} - I_{act} \qquad (3)$$

The output of PI controller is than compared with the 20 kHz sawtooth carrier signal to produce a pulse width modulation signal for constant current charging. Any change in the output current leads to actuate feedback controller to change duty ratio of switching pulses. The modelling of battery and SOC estimation are discussed in literature [18-19]. It is very helpful in changing mode from constant current to

constant voltage operation. Constant current charging is applied till the state of charge reaches 85%. Here after controller works on constant voltage charging mode and current exponentially decreases to zero.

5. SIMULATION OF CONSTANT CURRENT CONTROL CHARGING SCHEME

Using MATLAB software along with its SIMULINK toolboxes, the constant current charging scheme is simulated. Figure 7 shows the Schematic diagram of the constant current control scheme. It consists of a transformer, bridge rectifier, boost converter battery and subsystem of PI controller. Figure 8 shows the simulation model of PI controller. It generates the duty to control the switching pulses of boost converter using negative feedback control. TABLE II give the design specifications of transformer, filter and boost converter parameters which are used for simulation.

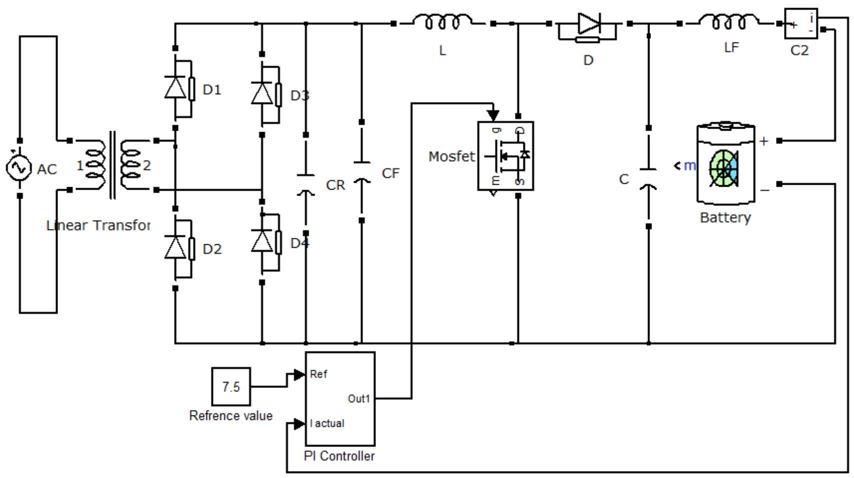

Figure 5. Schematic diagram of constant current control scheme.

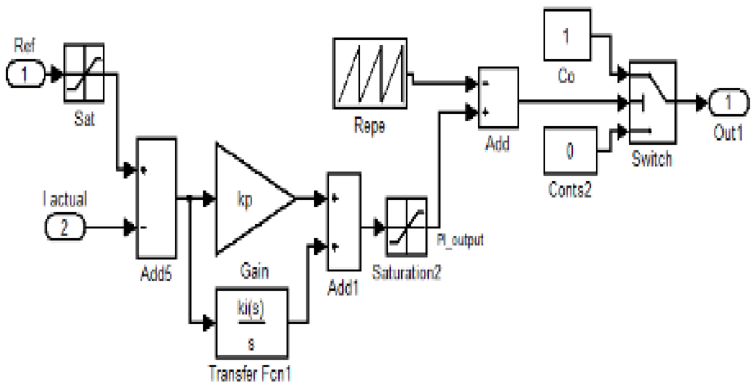

Figure 6. Schematic diagram of PI controller subsystem.

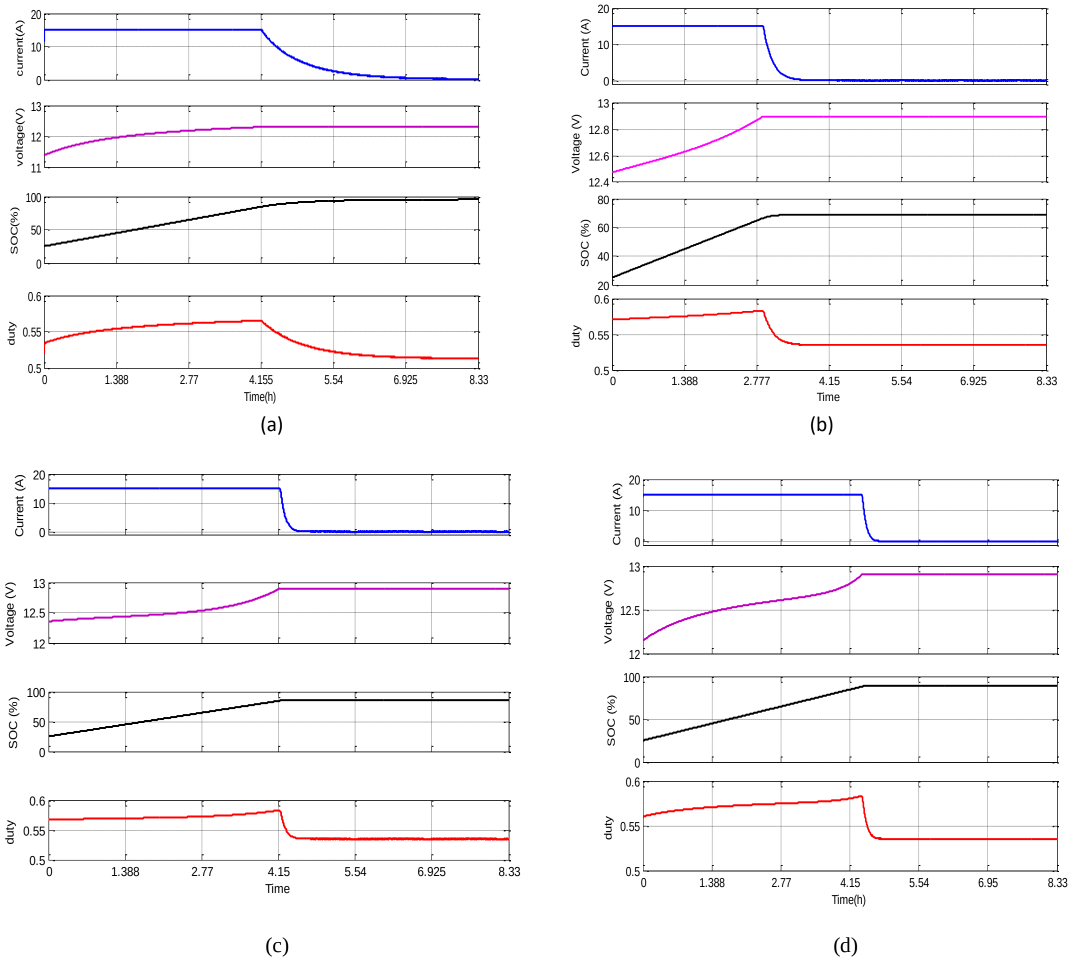

Figure 7. Charging profile of (a) Lead acid battery (b) Lithium ion battery (c) Nickel cadmium battery (d) Nickel Metal Hydride.

6. RESULTS AND ANALYSIS

Figure 7(a-d) shows the charging profile of four different 50 Ah, 12 V batteries operating under constant current and constant voltage charging mode. The battery models used are lead acid, nickel cadmium, lithium ion, and nickel metal hydride. The charging characteristic is shown in table 3 along with the comparison of charging time. The performance of four battery are compared which shows the charging time for lead acid battery is 5.33 hours, lithium ion battery is 3.46 hours, nickel cadmium battery is 4.30 hours and nickel metal hydride battery is 4.50 hours. The lithium ion battery is best suited for fast charging. Table 1 shows the specification of boost converter and Table 2 shows the design parameters of boost converter. Figure 8 to Figure 11 shows the transient results of control signals, switch, diode, inductor voltages and currents respectively. The simulation result validates the constant current operation of lithium ion battery charging.

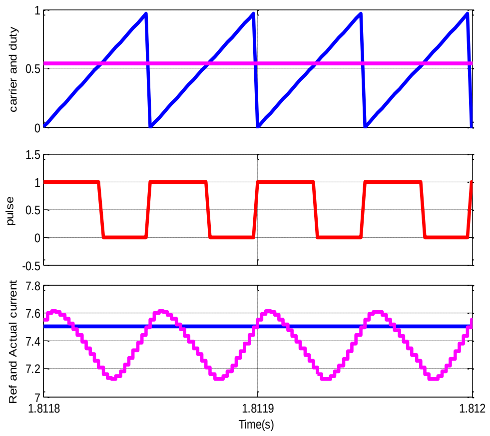

Figure 8. Results showing transient response of duty cycle carrier wave, gate pulses and output current for constant current operation

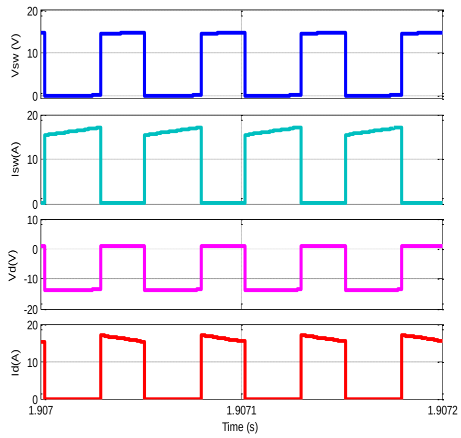

Figure 9. Results showing transient response of the switch, and diode voltages and currents respectively.

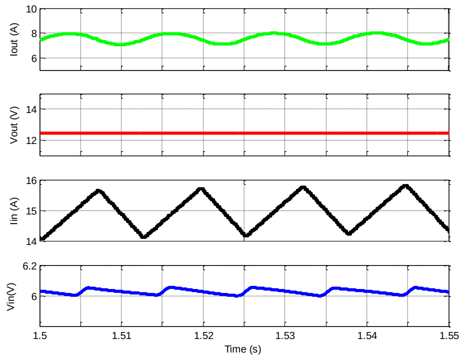

Figure10. Results showing transient response of boost converter input and output voltages and currents respectively.

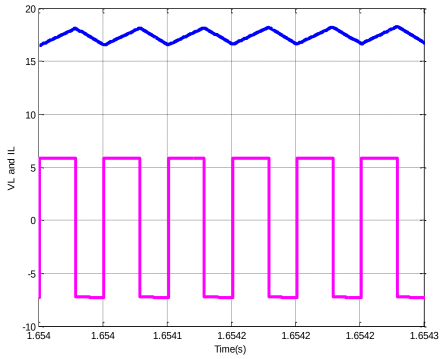

Figure11. Results showing transient response of inductor current and voltage.

Table 3.Comparision of chaging time for different types of batteries

Battery Type	Rating (Ah)	Constant current	Constant voltage	Total charging time (h)
Lead acid	50	7.5A	12.3 V	5.33
Lithium ion	50	7.5A	12.9 V	3.46
Nickel cadmium	50	7.5A	12.9 V	4.30
Nickel metal Hydride	50	7.5A	12.9 V	4.50

7. CONCLUSION

In this study a constant current charging system is realized using dc-dc boost converter. The proposed boost converter control scheme is able to produce a constant current charging of 7.5A. The charging performance and characteristics of different batteries was investigated which shows Lithium ion battery takes less charging time of 3.46 hour than other batteries. The design values of filter parameters and

boost converter parameters are calculated which gives excellent result and reduces the ripple within the prescribe limits. The bridge rectifier is used for ac voltage to dc conversion which is used to feed boost converter. ThePI controller is tuned to generate duty cycle for switching of boost converter to obtain constant current charging operation. Finally it can be concluded that, the constant current control strategy of charging can be used for higher power application such as electric vehicle battery and can also be implemented on large photovoltaic system.

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